(4)

Final Technical Report

on

ONR Contract #N00014-90-J-1915

"Theoretical Investigation of Some Novel Phenomenal in Artificially Structured Semiconductors"

Contents

This report covers the period 03/01/90 - 03/31/93

1. Summary of Scientific Results.

During the past three years my collaborators and I worked on problems in the following areas:

i) Double Quantum Well Systems

ii) Impurity Levels in Quantum Wells

iii) Diagrammatic Techniques for Finite Multilayer Structures

iv) Collective Excitations at Surfaces

v) Magnetic Polaron Effects

A brief summary of our findings on each of these topics is given below.

i) Double Quantum Well Systems

For an electron layer separated from a hole layer by a distance smaller than the "magnetic length", $l = (\hbar c/eB)^{1/2}$, the ground state in the presence of a strong magnetic field consists of a gas of free excitons. The excitons are bound states of an electron on one layer with a hole on the second layer. As the interlayer separation is increased, the system undergoes a phase transition to a new state which we called the "excitonic charge density wave state". This new state contains a spatially varying density of electrons, holes and excitons.

Our study of this system led us to investigate double electron layers and to attempt to understand the disappearance of the integral and fractional quantum Hall effect in two layer systems as the layer separation is increased. We also carried out numerical calculations for a system of six, seven or eight electrons on one layer interacting with a valence band hole on a neighboring layer. We discovered evidence for stable "angonic ions" in such systems. We are now looking into the spectrum of luminescence resulting from electron-hole recombination.

ii) Impurity Levels in Quantum Wells

For an impurity in the center of a quantum well which contains n_S subband electrons, the impurity state should be very sensitive to n_S and to applied magnetic field B_o. We have investigated the energy levels and transition energies of both D^o (neutral donors) and D^- (negatively charged donors) as a function of n_S and B_o, and we find fairly good agreement with experiment.

iii) Diagrammatic Techniques

We are frequently interested in properties of finite multilayer structures. Calculations of electronic states, phonons, magnons, etc., are rather tedious for more than three or four layers because of the arithmetic of keeping track of boundary conditions between layers. In a series of papers Dr. George Vecris and I developed and applied a novel diagrammatic method which greatly simplified these calculations.

iv) Collective Excitations at Surfaces

For an electron gas in which the electron density does not fall abruptly to zero at the surface, it is possible to have additional surface modes beyond the usual surface plasmon. These modes called "higher multiple modes" are bulk plasmons of the low density surface region. We are currently exploring such modes in degenerate semiconductors where the electron density profile can be tailored by compositional control in molecular beam epitaxy. The Raman scattering intensity due to higher multipole modes in artificially structured semiconductors is currently being investigated.

v) Magnetic Polaron Effects

The magnetic polaron effect in materials like $Cd_{1-x}Mn_xTe$ and $Zn_{1-x}Mn_xSe$ are well documented. Magnetic polarons are free carriers dressed by the induced polarization field of the magnetic ions. In a "mean field" approach to this problem, a non-linear Schrodinger equation results from the interaction of the free carrier and the magnetic ions. For a superlattice, the periodicity of the superlattice potential together with the non-linearity of the magnetic polaron effect leads to interesting and new behavior which we have reported and are continuing to study.

2. Personnel Supported (03/01/90 - 03/31/93)

a) Postdoctoral Research Associates

Xiaodong Zhu	1990-91
Ximing Chen	1991-93
Yun Zhu	1991-92
Xiaoguong Xia	1992-93

b) Graduate Students

Xiaoguong Xia	1990-92
George Vecris	1990 (Summer)

3.

Symposium for 65th Birthday of P.J. Bray, Providence, RI, June, 1990.

Workshop on Electronic Properties of Multilayer Structures, London, Ontario, August, 1991.

March Meeting of the American Physical Society, Indianapolis, IN, March, 1992.

Honorary Degree Lecture at Purdue University, May, 1992.

4. List of Publications Acknowledging ONR Support.

1. "A Novel Diagrammatic Method for the Analysis of Finite Multilayer Structures," (with G. Vecris), Proceedings of 20th International Conference on Physics of Semiconductors," Thessaloniki, Greece, 1990.

2. "Novel Diagrammatic Method for Analyzing the Surface Electronic Modes of Finite Multilayer Structures," (with G. Vecris), Proceedings of the International Conference on Solid Films and Surfaces, Providence, (1990).

3. "Novel Diagrammatic Method for the Analysis of Finite Periodic and Aperiodic Multilayer Structures," (with G. Vecris), Solid State Comm. 76, 1071 (1990).

4. "Exact Analytic Dispersion Relation for Dipolar Magnetostatic and Magnetoretarded Modes in Finite Superlattices, (with G. Vecris), Phys. Rev. B43, 8303 (1991).

5. "Excitonic Charge Density Wave Instability of Spatially Separated Electron-Hole Layers in a Strong Magnetic Field," (with X. Chen), Phys. Rev. Lett. 67, 895, (1991).

6. "Tunneling in a Periodic Array of Semimagnetic Quantum Dots," (with Hawrylak and Grabowski), Phys. Rev. B44, 13082 (1991).

7. "Excitonic Charge Density Wave State of Spatially Separated Electron-Hole Layers in a Magnetic Field," *Excitation in Superlattices and Multiple Quantum Wells*, Proceedings of Workshop at London, Ontario, ed. by Cottam and Singh, Springer Verlag (1991).

8. "Hydrogenic Impurities in Quasi Two-Dimensional Electron Gas Systems," (with X. Xia and X. Zhu), Phys. Rev. B45, 1341 (1992).

9. "Excitonic Charge-Density Wave: A Novel Phase of Double Quantum Well Systems," (with Chen), Mod. Physics Letters B6, 145 (1992).

10. "Magnetoexcitons in GaSb-AlSb-InAs Quantum Well Structures," (with Xia and Chen), in Phys. Rev. B46, 7212 (1992).

11. "Correlated Charge Density Wave States of Double Quantum Well Systems in A Strong Magnetic Field," (with Chen), Phys. Rev. B 45, 11054 (1992).

12. "Multipole Plasmon Modes at the Surface of A Conducting Solid," in Solid State Comm. 84, 139 (1992).

13. "Transition Energies of D^- Levels in Quantum Well Structures," (with Xia), Phys. Rev. B46, 12530 (1992).

14. "Collapse of Fractional Quantum Hall States in Double Quantum Well Systems," (with Xia and Chen), Phys. Rev. B46 15526 (1992).

15. "Collective Excitations of an Electron Wigner Lattice in a Double Quantum Well System, (with Chen), Phys. Rev. B47, 3999 (1993).

16. "Numerical Study of Fractional Quantum Hall Electron-Hole Systems: Evidence for Stable Anyonic Ions", (with Chen) submitted to Physical Review Letters 70, 2130 (1992).

17. "Numericals Study of Fractional Quantum Hall Electron-Hole Systems: Evidence for Stable Anyonic Complexes," (with Chen) to appear in Proc of EP2DS, Newport, RI (1993).